FORM PTO-1390 (REV 11-2000)	U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 117-373
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U S APPLICATION NO (If known, see 37 C F.R 1.5) 10/019220 Unknown
INTERNATIONAL APPLICATION NO. **PCT/GB00/02504**	INTERNATIONAL FILING DATE **29 June 2000**	PRIORITY DATE CLAIMED **29 June 1999**

TITLE OF INVENTION

AMPEROMETRIC SENSOR

APPLICANT(S) FOR DO/EO/US

LAU et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☒ The U.S. has been elected by the expiration of 19 months from the priority date (Article 31).
5. A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has **NOT** expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 To 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information. PTO-1449 and copy of International Search Report

U.S. APPLICATION NO (If known, see 37 C.F.R. 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
10/019220 Unknown	PCT/GB00/02504	117-373

21. ☒ The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):		
-- Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00		
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $890.00		
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO $740.00		
-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) $710.00		
-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE			
Total Claims	22	-20 =	2	X	$18.00	$ 36.00	
Independent Claims	2	-3 =	0	X	$84.00	0.00	
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)					$280.00	$ 0.00	
					TOTAL OF ABOVE CALCULATIONS =	$ **1056.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.						0.00	
					SUBTOTAL =	$ **1056.00**	
Processing fee of $130.00, for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(f)). +						0.00	
					TOTAL NATIONAL FEE =	$ **1056.00**	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). **$40.00** per property +						$ 0.00	
Fee for Petition to Revive Unintentionally Abandoned Application ($1280.00 – Small Entity = $640.00)						$ 0.00	
					TOTAL FEES ENCLOSED =	$ **1056.00**	
					Amount to be: refunded	$	
					Charged	$	

a. ☒ A check in the amount of $1056.00 to cover the above fees is enclosed.
b. ☐ Please charge my Deposit Account No. 14-1140 in the amount of $_____ to cover the above fees. A duplicate copy of this form is enclosed.
c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1140. A duplicate copy of this form is enclosed.
d. ☒ The entire content of the foreign application(s), referred to in this application is/are hereby incorporated by reference in this application.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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SIGNATURE

Arthur R. Crawford
NAME

25,327 **December 28, 2001**
REGISTRATION NUMBER Date

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

LAU et al Atty. Ref.: **117-373**

Serial No. **Unknown** Group:

National Phase of: **PCT/GB00/02504**
International Filing Date: **29 June 2000**

Filed: **Herewith** Examiner:

For: **AMPEROMETRIC SENSOR**

* * * * * * * * * * *

December 28, 2001

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

PRELIMINARY AMENDMENT

Prior to calculation of the filing fee and in order to place the above identified application in better condition for examination, please amend as follows:

IN THE SPECIFICATION

Page 1, after the title insert the following:

-- This application is the US national phase of international application PCT/GB00/02504 filed June 29, 2000 which designated the U.S. --.

IN THE CLAIMS

Please cancel claims 1 through 21 and substitute therefor new claims 22 through 43 as follows:

22. New) An amperometric sensor suitable for determining the concentration of hydrogen peroxide in a sample, said sensor comprising a ferricyanide compound which, in reduced form, functions as a mediator selective for hydrogen peroxide.

23. (New) A sensor according to claim 22 further comprising an enzyme which is capable of reacting with an analyte in the sample to produce hydrogen peroxide.

24. (New) A sensor according to claim 23, wherein the analyte is glucose and the enzyme is glucose oxidase.

25. (New) A sensor according to claim 22, wherein the ferricyanide compound is of general formula:

$$X_3 Fe (CN)_6$$

in which the groups X are the same or different and at least one X is a non-metallic ion.

26. (New) A sensor according to claim 25, in which each X is a quaternary ainmonium ion of formula (R^1) (R^2) (R^3) (R^4) N^+ in which Ri^1 to R^4 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that at least one of R^1 to Ri^4 contains at least 4 carbon atoms.

27. (New) A sensor according to claim 26, wherein the ferricyanide compound is tetrahexylammonium ferricyanide, tetrakisdecylammonium ferricyanide, tetradecyltrimethylammonium ferricyanide, hexadecyltrimethylammonium ferricyanide or trimethylhexylammonium ferricyanide.

28. (New) A sensor according to claim 25, wherein each X is a phosphonium ion of formula (R^5) (Ri^6) (R^7) (R^8) P^+ in which R^5 to R^8 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that at least one group R^5 to R^8 contains at least 4 carbon atoms.

29. (New) A sensor according to claim 25, wherein each X is a nitrogen-containing heterocyclic cation.

30. (New) A sensor according to claim 29, wherein each X is a pyridinium ion.

31. (New) A sensor according to claim 22, in which the ferricyanide compound is bound to a polymer.

32. (New) A sensor according to claim 31 wherein the polymer is a polyacrylamide.

33. (New) A sensor according to claim 31, wherein the ferricyanide compound is bound to the polymer via one of groups R^1 to R^4 of a quatemary ammonium ion of formula

$$(R^1)\ (R^2)\ (R^3)\ (R^4)\ N^+$$

or via one of groups R^5 to R^8 of a quatemary phosphonium ion of formula

$$(R^5)\ (R^6)\ (R^7)\ (R^8)\ P^+$$

or via a nitrogen-containing heterocyclic cation.

34. (New) A sensor according to claim 31 wherein the ferricyanide compound is polypyridinium ammonium ferricyanide or poly(acrylamide-co-diethyldimethyl ammonium) ferricyanide.

35. (New) A cartridge for an amperometric sensor suitable for measuring hydrogen peroxide in a sample, which cartridge comprises a ferricyanide compound as defined in claim 22.

36. (New) A cartridge according to claim 35, further comprising an enzyme as defined in claim 2.

37. (New) A cartridge according to claim 35, further comprising an enzyme as defined in claim 3.

38. (New) Use of an amperometric sensor as claimed in claim 22, for determining the concentration of hydrogen peroxide in a sample.

39. (New) Use of an amperometric sensor as claimed in claim 23 for determining the concentration of an analyte in a sample, wherein the enzyme of the sensor reacts with the analyte to produce hydrogen peroxide.

40. A ferricyanide compound of formula:

$$X_3 Fe (CN)_6$$

in which the groups X are the same or different and each is a quaternary ammonium ion, at least one of the quaternary ammonium ions having (a) four identical alkyl groups of 5 to 11 carbon atoms other than heptyl or (b) three methyl groups and an alkyl group of 6 to 20 carbon atoms other than hexadecyl.

41. (New) A compound according to claim 40 wherein each X is a quatemary ammonium ion selected from hexyltrimethylammonium, heptyltrimethylammonium, octyltrimethylammonium, nonyltrimethylammonium, decyltrimethylammonium, tetradecyltrimethylammonium, hexadecyltrimethylammonium, tetrahexylammonium and tetrakisdecylammonium.

42. (New) A compound according to claim 40 wherein the groups X are all the

same.

43. A process for preparing a ferricyanide compound as defined in claim 40, which process comprises reacting

(i) a quaternary ammonium halide having (a) four identical alkyl groups of *5* to 11 carbon atoms other than heptyl or (b) three methyl groups and an alkyl group of 6 to 20 carbon atoms other than hexadecyl with

(ii) an alkali metal ferricyanide salt.

LAU et al
Serial No. **Unknown**

REMARKS

The above amendments are made remove multiple dependencies and to place the claims in a more traditional format.

Respectfully submitted,
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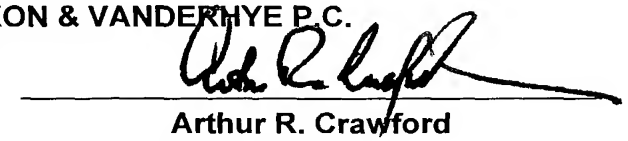
By: 
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AMPEROMETRIC SENSOR

In general terms the present invention relates to the determination of the concentration of an analyte in a sample. More specifically, the invention relates to an amperometric sensor, to its use, to cartridges for the sensor and to redox mediator compounds for use in the sensor.

A number of electrochemical sensors (or biosensors) have been proposed previously. For example, US 5, 288, 636 describes a sensor useful for determining glucose concentration in a sample and relies on the reaction between the enzyme glucose oxidase and glucose with the mediator potassium ferricyanide to produce a ferrocyanide which is then electro-oxidised to produce a measurable current that is representative of the concentration of glucose present.

The reactions involved can be summarised as follows:

1. GOD_{OX} + glucose $\rightarrow$ gluconic acid + GOD_{RED}

2. $GOD_{RED} + M_{OX} \rightarrow GOD_{OX} + M_{RED}$

3. $M_{RED} \rightarrow M_{OX} + e^-$ [Signal]

GOD_{OX} - oxidised form of glucose oxidase
GOD_{RED} - reduced form of glucose oxidase
M_{OX}- oxidised form of mediator (ferricyanide)
M_{RED} - reduced form of mediator (ferrocyanide)

In step 1 the enzyme oxidizes the glucose and is itself reduced. In step 2 the reduced form of the enzyme reacts with the oxidised form of the mediator to produce the reduced form of the mediator. In step 3 the oxidised form of the mediator is regenerated by electro-oxidation. A measurable current/signal is generated. Thus,

this type of sensor depends on reaction between the mediator and enzyme.

US 4,711,245 also describes a sensor for determining glucose concentration. The sensor relies on a reaction involving the enzyme glucose oxidase, glucose and the oxidised form of a substituted ferrocene. The ferrocene is reduced and then re-oxidised to produce an easily measurable current.

There are several disadvantages associated with known sensors. Firstly, the mediators used can be unstable and tend to undergo autoxidation Secondly, in known sensors a potential is applied between electrodes in order to oxidise the reduced form of the mediator. At potentials which are sufficient to achieve this interferants present in the system, for example ascorbates, urate and paracetamol, tend to be oxidised. Both of these effects lead to inaccurate measurement of analyte concentration. In the latter case, the analyte concentration is typically overestimated due to a non-specific oxidation current. With respect to this particular problem, it would be advantageous to use the sensor at assay potentials more negative than +100 mV (Ag/Ag Cl) to avoid measuring signal due to common interferants.

The present invention solves these problems by use of a sensor which relies on the reaction between a mediator compound and hydrogen peroxide. The hydrogen peroxide may be the analyte it is desired to assay or it may be the product of an enzyme-analyte reaction. An important feature of the sensor is that in the reduced form the mediator can be detected electrochemically at a potential of about -400 mV (Ag/AgCl). At such a potential, oxidation of common interferants is avoided.

Accordingly, the present invention provides an amperometric sensor suitable for determining the concentration of hydrogen peroxide in a sample, said sensor comprising a ferricyanide compound which, in reduced form, functions as a mediator selective to hydrogen peroxide.

The sensors of the invention may, of course, be used to determine the concentration of hydrogen peroxide in a sample. However, as is evident from the reaction scheme above, hydrogen peroxide may be generated as a product of an analyte-enzyme reaction, such as between glucose and glucose oxidase. The sensors can therefore be used to determine the concentration of such analytes. In this

embodiment the sensor further comprises an enzyme which is capable of reacting with the analyte in a sample to produce hydrogen peroxide. Typically, the enzyme will be an oxidase type enzyme. For example, in a sensor for determining the concentration of glucose in a sample, the enzyme may be glucose oxidase. The reaction between the enzyme and analyte yields hydrogen peroxide in the presence of oxygen, and the concentration of the hydrogen peroxide can be determined using the sensor and correlated to a corresponding glucose concentration Other analytes which may be determined using the sensor of the present invention include chloresterol, pyruvate, bilirubin, alcohol and lactate; USP 5,288,636 gives details of the relevant enzymes and mediators.

Further analytes may be measured if suitable additional enzymes and/or mediators are included in the sensor. Examples of this include triglycerides and HDL cholesterol. Of course the sensors should be constructed so that the final product of the enzyme reactions detected by the ferricyanide mediator, is hydrogen peroxide.

Herein the term "mediator" means a compound which is capable of undergoing an electrochemical, reversible oxidation-reduction reaction.

The mediator used in the present invention is a ferricyanide compound which in reduced form is selective for hydrogen peroxide, i.e. which is oxidised on reaction with hydrogen peroxide. Examples of suitable compounds include those of general formula (I)

$$X_3Fe(CN)_6 \qquad (I)$$

in which the groups X are the same or different and each is a non-metallic ion or any other organic or inorganic species provided that at least one group X is a non-metallic ion and provided that the compound of formula (I) has satisfactory solubility in water and common organic solvents.

Solubility of the compound of Formula (I) is an important factor in the proper functioning of the sensor. Low solubility in water and aqueous phases is helpful in providing stability and conveniently the compound of Formula (I) should have a solubility of from 2000 mg/L to 20,000 mg/L in pure water. Solubility in common organic solvents is desirable to facilitate fabrication of the sensors and conveniently

the compound of Formula (I) will have a solubility of at least 20,000 mg/L and preferably higher, in at least one of methanol, ethanol, propanol, other lower alkanols, chloroform, dichloromethane or other chlorinated alkanes and acetone and other low molecular weight ketone and ether solvents.

Groups X may be selected from any known organic or inorganic groups and ions subject to the above restrictions. Examples of groups X include all metal ions, especially all monovalent metal ions and particularly all alkali metal ions such as sodium and potassium ions. Other suitable groups X include quaternary ammonium ions and quaternary phosphonium ions.

Preferably the mediator is specific to hydrogen peroxide, i.e. under the conditions of the analysis, the mediator only provides electrons for hydrogen peroxide. In practice it is likely that this will be the case when operating at the preferred potential (see below). However specificity is not essential and the system may be operated satisfactorily provided that the mediator is selective for hydrogen peroxide, i.e. under the conditions of the analysis the mediator tends to provide electrons to hydrogen peroxide in preference to any other electron acceptor available to the mediator.

In this formula X may be a quaternary ammonium ion, for instance of formula (II)

$$(R^1)(R^2)(R^3)(R^4)N^- \qquad (II)$$

in which R^1 to R^4 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that a least one of R^1 to R^4 contains at least 4 carbon atoms. Typically, R^1 to R^4 are selected from amongst alkyl groups containing from 4 to 20 carbon atoms, preferably from 4 to 16 carbon atoms. Conveniently the quaternary ammonium ion will have four identical alkyl groups in which case the alkyl groups are preferably selected from those of 5 to 11 carbon atoms. As an alternative the quaternary ammonium ions may conveniently have only one long chain alkyl group and three identical short chain alkyl groups such as methyl groups. In this case the long chain alkyl group is preferably selected from those of 6 to 20 carbon atoms.

The longer alkyl groups render the quaternary ammonium ions relatively insoluble which is an advantage in the present invention. It is preferred that the

quaternary ammonium ions used have a solubility of not more than 100 $mg.L^{-1}$ in water at room temperature (20 C), more preferably not more than 10 $mg.L^{-1}$ and most preferably not more than 1 $mg.L^{-1}$. As specific examples of useful compounds there may be mentioned tetrahexyl-, hexyltrimethyl-, tetrakisdecyl-, tetradecyltrimethyl- and hexadecyltrimethylammonium ferricyanides.

In another embodiment of the invention, the group X may be a phosphonium ion, for example of formula $(R^5)(R^6)(R^7)(R^8)P^+$ in which R^5 to R^8 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that at least one group R^5 to R^8 contains at least 4 carbon atoms.

In a further embodiment the group X may be a nitrogen-containing heterocyclic cation. The heterocyclic group may be saturated, unsaturated or aromatic. As an example, X as pyridinium may be mentioned.

The alkyl groups mentioned above may be straight or branched-chain. The alkyl and heterocyclic groups may be substituted by one or more substituents provided that these do not have a detrimental effect on the activity of the mediator compounds.

In a particular embodiment of the invention the ferricyanide anions $[Fe(CN)_6]^{3-}$ may be bound to a polymeric support via functional groups on the polymer. One class of such functional groups includes the quaternary ammonium ions

$$(R^1)(R^2)(R^3)(R^4)N^+$$

wherein one of R^1 to R^4 is the polymeric backbone and the other groups are as defined above. Another class of such functional groups includes the quaternary phosphonium ions

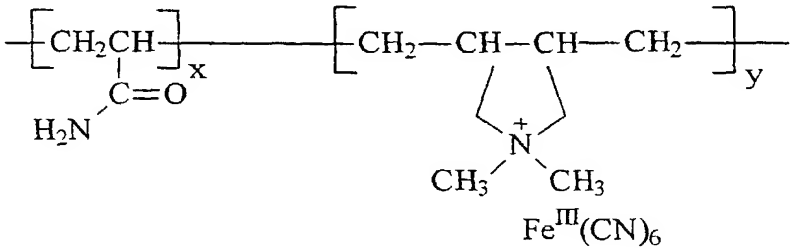
$$(R^5)(R^6)(R^7)(R^8)P^+$$

in which one of R^5 to R^8 is the polymeric backbone and the other groups are as defined above. A further class of such functional groups includes nitrogen-containing heterocyclic cations which may be saturated, unsaturated or aromatic such a pyridinium and where the heterocyclic moiety is bound to or forms part of the polymeric backbone.

Suitable polymers are well known to those skilled in the art and may be

readily produced by conventional techniques. Derivatisation with suitable functional groups may be achieved, when necessary, by known methods.

In a preferred embodiment the polymers have gel-forming properties. This may be achieved using gel-forming blocks within the polymer coupled with functional group-bearing blocks or by forming random copolymers having gel-forming and functional moieties. Included within the gel forming polymers are functionalised polyacrylamides and polymers of a block structure such as



Polymers may be soluble in water or insoluble but preferably have a solubility less than 20,000 mg/L and preferably have film or gel-forming properties.

Some of the compounds useful as mediators are known and are commercially available. Alternatively, they may be made by the application or adaptation of known techniques. Certain of the mediator compounds are new however and these form another aspect of the present invention. Thus, the invention also provides novel ferricyanide compounds of the above formula in which at least one X is a quaternary ammonium ion having at least one C_6 to C_{20} alkyl group other than tridodecylmethyl-, methyltrioctyl-, dihexadecyldimethyl-, didodecyldimethyl-, hexadecyltrimethyl and tetraoctylammonium ions.

These ferricyanide compounds may be prepared by methods described in Svitel, J. *et al.*, Electroanalysis, 1998, 10, No. 9, pp 591-596, and modifications thereof, using appropriate quaternary ammonium halides and ferricyanide salts. In general, a quaternary ammonium halide such as the chloride or preferably the bromide, is reacted with a ferricyanide salt, preferably an alkali metal salt such as sodium or, more preferably, potassium ferricyanide. The reaction may be conducted under suitable conditions of temperature and pressure, such as at room temperature or

elevated temperature up to the boiling point of the reaction mixture, and at atmospheric pressure, and for sufficient duration such as from a few minutes to a few hours, preferably at 80°C for 2 hours, in the presence of a suitable solvent such as water.

The mediator compounds disclosed herein are useful in a variety of amperometric sensor devices and electrode configurations. The sensors may be based on a 2 or 3 electrode system and may be of the disposable (single use) or re-usable/semi-disposable type.

In its simplest form the sensor comprises two electrodes (working and counter) which in use are contacted with the sample being analysed. One electrode, the working electrode, is coated with the mediator compound. The mediator is sparingly soluble or insoluble in aqueous solution and may be applied to the electrode by deposition from a solution of the mediator in a readily evaporable organic liquid. When the sensor is being used to determine the concentration of an analyte such as glucose the mediator is coated with a suitable enzyme. The enzyme can be immobilised on the surface of the mediator by conventional techniques such as by use of a self-sustaining gel layer and/or by use of a retention layer which is permeable to the analyte. US 4,711,245 describes in greater detail ways in which the mediator and, when used, enzyme may be fixed on the working electrode.

The electrode substrate is chosen from conventional materials such as carbon pellets, carbon inks, metallized carbon and metals (such as platinum or palladium), carbon rods, pencil leads and carbon rods loaded with metal powder.

Conventional electrode configurations which may be used include those disclosed in US 4,711,245, US 5,200,051 and US 5,288,636, incorporated herein by reference.

The basic chemical and electrochemical transformations associated with the present invention are shown below with reference to the glucose/glucose oxidase system. Prior to introduction of the sample to be analysed a potential of about -400mV (Ag/AgCl) is applied to the sensor electrode. This potential is sufficient to cause reduction of the mediator at the working electrode, i.e. conversion of the ferricyanide to the corresponding ferrocyanide. When the electrodes are contacted

with the sample to be analysed the enzyme at the working electrode acts on the glucose resulting in the production of hydrogen peroxide. The reaction proceeds as shown in reaction scheme 4 below.

$$GOD_{RED} + O_2 \rightarrow GOD_{OX} + H_2O_2$$

The hydrogen peroxide produced oxidises the reduced form of the mediator as follows:

$$M_{RED} + H_2O_2 \xrightarrow{2H^+} 2H_2O + M_{OX}$$

$$M_{OX} \xrightarrow{2e^-} M_{RED}$$

Instantaneously, under the applied potential, the oxidised form of the mediator at the working electrode is converted to the reduced form and a diffusion limited current generated. This current can be measured and correlated to the concentration of analyte in the sample.

At the electrode potential involved (-400 mV) there is no oxidation of interferants and the result obtained is an accurate reflection of the hydrogen peroxide concentration in the sample. The hydrogen peroxide concentration may be correlated to analyte concentration.

A diffusion limiting layer may be applied to the working electrode to extend the sensor to measurement of higher analyte concentrations. Examples of materials for use as the diffusion-limiting include Nafion™ and cellulose acetate.

It is envisaged that the sensors of the invention will find most practical utility in the measurement of glucose in blood samples, although they may also be used for other medical and non-medical applications, for example in the food industry.

Brief description of the accompanying drawings:

Figure 1:

CV of hydrogen peroxide sensor showing the responses to background buffer solution and the increased responses when 200 uL and 700uL 131mM hydrogen peroxide were added into 4ml buffer. The scan rate used was 50mV/s.

Figure 2:

The calibration trace for THAF mediated hydrogen peroxide sensor on addition of 88mM hydrogen peroxide solution.

Figure 3.

Calibration plot for THAF mediated hydrogen peroxide sensor.

Figure 4:

CV of hydrogen peroxide sensor in the presence of glucose oxidase in solution showing the responses to different concentration of glucose. The scan rate used was 100 mV/s.

Figure 5:

The calibration trace for THAF mediated glucose sensor on standard addition of 50mM glucose solution.

Figure 6:

Calibration plot for THAF mediated glucose sensor.

The following Examples illustrate the invention but are not intended to limit the scope of protection in any way.

EXAMPLES

Example 1 Synthesis of mediator

Tetrahexylammonium ferricyanide (THAF) was prepared by adding an aqueous solution of potassium ferricyanide (Aldrich, Dorset, U.K.) (0.5mmole 1.65g) into a solution of tetrahexylammonium bromide (Aldrich, Dorset, U.K.) (1.5mmole, 0.65g) in 20ml of distilled water and heating the mixture to 80°C for 2 hr with vigorous stirring. A yellow coloured oil separated from the aqueous phase and was extracted with diethylether (3x10ml). The ethereal extract was washed with distilled water (3x10ml) and then dried over magnesium sulphate. Evaporating the solvent gave 1.1g of yellow oil which solidified on standing.

Example 2 Electrode construction

A silver loaded carbon pellet (Electrocarbon, Norfolk, U.K.) with a diameter of 2mm and a length of 4mm was fitted with a 1.8mm internal diameter PVC rubber tubing section (4mm in length) so that a recess of about 1mm was left at one end. The other end of the pellet was fixed to a 5cm long copper wire with silver expoxy glue as contact. The whole assembly was then fitted into another 4.5cm long PVC tubing that fitted the electrode assembly tightly. The opening at the end of the tubing with exposed contact wire was then sealed with epoxy glue. The finished electrode assembly has an electrode area of 3.1mm^2.

Example 3 Hydrogen peroxide sensor

1uL of a 5.5% ethanolic solution of THAF (Example 1) was deposited onto the recess of the electrode prepared in Example 2 and allowed to dry for 3 minute. A 1uL aliquot of Nafion™ solution (5% solution from Aldrich, Dorset, U.K.) in distilled water (9:1 mixture, final concentration 0.5%) was deposited on top of the ferricyanide layer to form a diffusion control membrane. The sensor was air-dried for at least 4 hr before use.

Example 4 Glucose sensor

This biosensor was formed in a manner similar to that for the hydrogen peroxide sensor of Example 3 except that an enzyme layer was added in between the ferricyanide layer and the diffusion control layer. The enzyme layer used was made from two solutions:

Solution A: propanoic solution containing 2.2% THAF and 1.25% Nafion™.

Solution B: glucose oxidase solution (5mg/ml about 200U/mg) (Fluka, Dorset, U.K.).

A 1:1 mixture of solution A and solution B was prepared immediately before use and a total of 10ul were deposited onto the THAF modified electrode in 2uL aliquots. The sensor was dried in a gentle stream of air (about 30min,) before a 1uL aliquot of 0.5% Nafion™ solution in water was deposited over the enzyme layer. The sensor was air dried as before and kept dry at 4°C overnight before use.

Example 5 Use of Hydrogen peroxide sensor

Cyclic voltammetry was used to show the activity of this sensor to hydrogen peroxide. A three electrode system was used with the sensor of Example 3 as the

working electrode, a platinum electrode as the counter electrode and a silver-silver chloride electrode as the reference electrode. An AutoLab (Eco Chemie B.V.) electrochemical system was used for the measurements. Cyclic voltammetry at a scan rate of 50mV/s and a scan range of -1.0V to 1.5V vs Ag-AgCl shows the increase in cathodic current when aliquots of 131mM hydrogen peroxide (200uL and 700uL) in phosphate saline buffer solution were added into 4ml of the same buffer solution at pH 7.4 (Fig-1). The same cell set up was used for calibration of the sensor by amperometry; the current measured at the hydrogen peroxide sensor at an applied potential of -400mV vs Ag-AgCl during an experiment where aliquots of 131mM hydrogen peroxide in phosphate saline buffer were added to 4ml of the same buffer was plotted (Fig.2) A calibration plot (Fig.3) resulting from the amperometry data shows a linear range from 0 to about 20mM hydrogen peroxide.

Example 6 Use of Hydrogen Peroxide sensor

Similar experiments to those of Example 5 were carried out using the hydrogen peroxide sensor of Example 3 in the same cell set up, except that the counter electrode used was a gold electrode. For all cases the buffer used for making up glucose solution and the blank (background) was phosphate saline buffer at pH7.4. 200 uL of glucose oxidase solution (5 mg/mL, Fluka) was added into 4 mL buffer solution before the cyclic voltammetry studies. The scan rate for cyclic voltammetry measurement was 100mV/s and the scan range used was 0.15V to -0.55V. The cyclic voltammagram (Fig.4) obtained for different glucose concentrations shows cathodic currents at around -400 mV that indicate that the biosensor responded to hydrogen peroxide, which was produced by the action of the glucose oxidase on the glucose added and that the increase in cathodic current was concentration dependent.

Example 7 Use of Glucose Sensor

Similar experiments to those of Example 6 were carried out using the glucose sensor of Example 4 in the same cell set up. For all cases the buffer used for making up glucose solution and the blank (background) was phosphate saline buffer at pH7.4. The current measured at the glucose sensor at an applied potential of -400mV

vs Ag-AgCl during an experiment where aliquots of 50 mM glucose in phosphate saline buffer were added to 4 ml of the same buffer shows a linear range from 0 to about 30 mM glucose (Figs. 5 and 6).

CLAIMS

1. An amperometric sensor suitable for determining the concentration of hydrogen peroxide in a sample, said sensor comprising a ferricyanide compound which, in reduced form, functions as a mediator selective for hydrogen peroxide.

2. A sensor according to claim 1, further comprising an enzyme which is capable of reacting with an analyte in the sample to produce hydrogen peroxide.

3. A sensor according to claim 2, wherein the analyte is glucose and the enzyme is glucose oxidase.

4. A sensor according to any one of claims 1 to 3, wherein the ferricyanide compound is of general formula:

$$X_3\ Fe\ (CN)_6$$

in which the groups X are the same or different and at least one X is a non-metallic ion.

5. A sensor according to claim 4, in which each X is a quaternary ammonium ion of formula $(R^1)\ (R^2)\ (R^3)\ (R^4)\ N^+$ in which R^1 to R^4 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that a least one of R^1 to R^4 contains at least 4 carbon atoms.

6. A sensor according to claim 5, wherein the ferricyanide compound is tetrahexylammonium ferricyanide, tetrakisdecylammonium ferricyanide, tetradecyltrimethylammonium ferricyanide, hexadecyltrimethylammonium ferricyanide or trimethylhexylammonium ferricyanide.

7. A sensor according to claim 4, wherein each X is a phosphonium ion of formula $(R^5)\ (R^6)\ (R^7)\ (R^8)\ P^+$ in which R^5 to R^8 are the same or different alkyl groups containing from 1 to 20 carbon atoms, provided that at least one group R^5 to R^8 contains at least 4 carbon atoms.

8. A sensor according to claim 4, wherein each X is a nitrogen-containing heterocyclic cation.

9. A sensor according to claim 8, wherein each X is a pyridinium ion.

10. A sensor according to any one of claims 1 to 9 in which the ferricyanide compound is bound to a polymer.

11. A sensor according to claim 10 wherein the polymer is a

polyacrylamide.

12. A sensor according to claim 10 or claim 11 wherein the ferricyanide compound is bound to the polymer via one of groups R^1 to R^4 of a quaternary ammonium ion of formula

$$(R^1)(R^2)(R^3)(R^4)N^+$$

or via one of groups R^5 to R^8 of a quaternary phosphonium ion of formula

$$(R^5)(R^6)(R^7)(R^8)P^+$$

or via a nitrogen-containing heterocyclic cation.

13. A sensor according to claim 10 wherein the ferricyanide compound is polypyridinium ammonium ferricyanide or poly(acrylamide-co-diethyldimethyl ammonium) ferricyanide.

14 A cartridge for an amperometric sensor suitable for measuring hydrogen peroxide in a sample, which cartridge comprises a ferricyanide compound as defined in any one of claims 1 and 4 to 13.

15. A cartridge according to claim 14, further comprising an enzyme as defined in claim 2 or 3.

16. Use of an amperometric sensor as claimed in any one of claims 1 and 3 to 13 for determining the concentration of hydrogen peroxide in a sample.

17. Use of an amperometric sensor as claimed in claim 2 for determining the concentration of an analyte in a sample, wherein the enzyme of the sensor reacts with the analyte to produce hydrogen peroxide.

18. A ferricyanide compound of formula:

$$X_3\,Fe\,(CN)_6$$

in which the groups X are the same or different and each is a quaternary ammonium ion, at least one of the quaternary ammonium ions having (a) four identical alkyl groups of 5 to 11 carbon atoms other than heptyl or (b) three methyl groups and an alkyl group of 6 to 20 carbon atoms other than hexadecyl.

19. A compound according to claim 18 wherein each X is a quaternary ammonium ion selected from hexyltrimethylammonium, heptyltrimethylammonium, octyltrimethylammonium, nonyltrimethylammonium, decyltrimethylammonium, tetradecyltrimethylammonium, hexadecyltrimethylammonium, tetrahexylammonium

and tetrakisdecylammonium.

20 A compound according to claim 18 or claim 19 wherein the groups X are all the same.

21. A process for preparing a ferricyanide compound as defined in claim 18, which process comprises reacting

(i) a quaternary ammonium halide having (a) four identical alkyl groups of 5 to 11 carbon atoms other than heptyl or (b) three methyl groups and an alkyl group of 6 to 20 carbon atoms other than hexadecyl with

(ii) an alkali metal ferricyanide salt.

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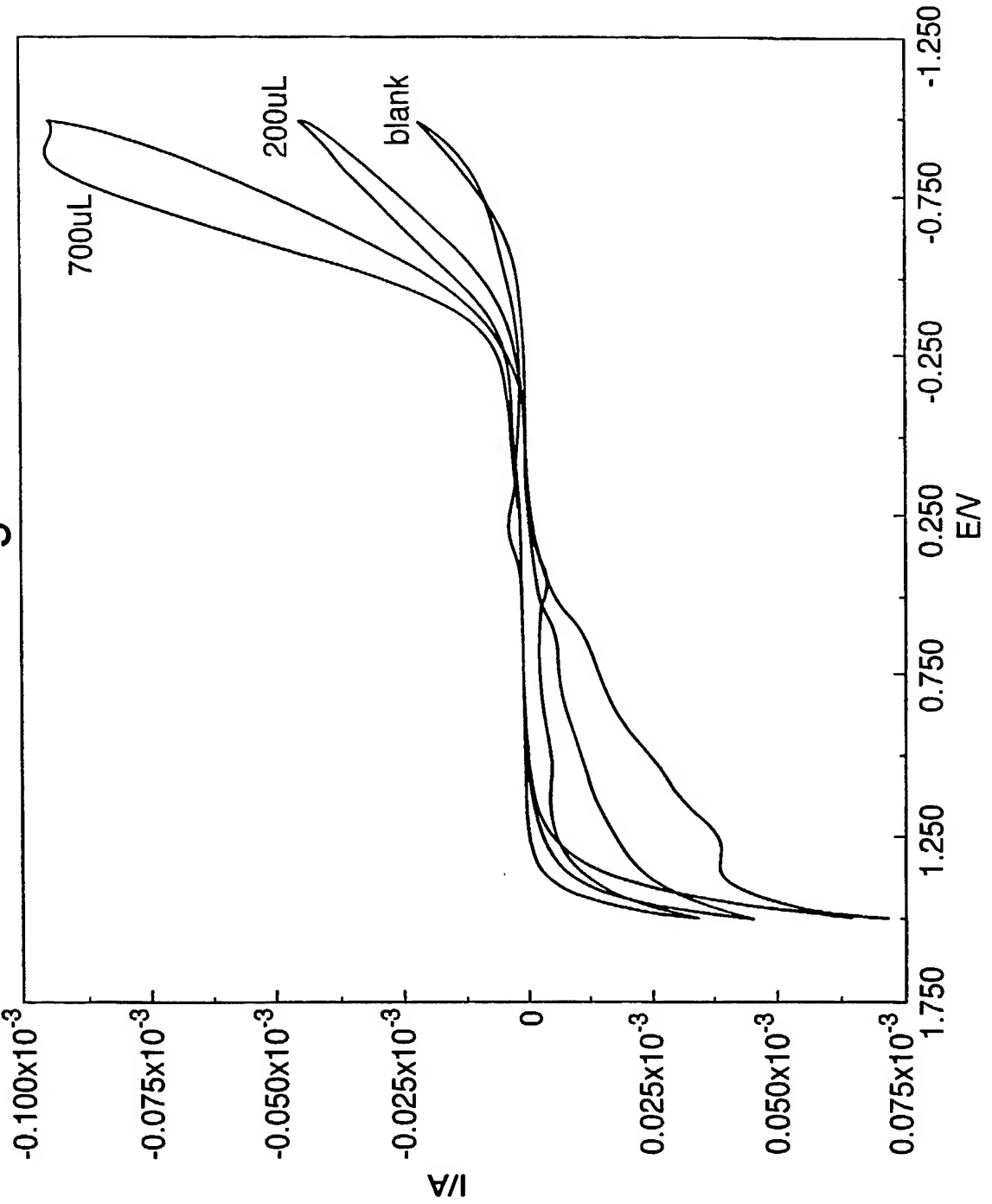
(54) Title: AMPEROMETRIC SENSOR

(57) Abstract: An amperometric sensor suitable for determining the concentration of hydrogen peroxide in a sample, said sensor comprising a ferricyanide compound which, in reduced form, functions as a mediator specific to hydrogen peroxide.

Fig.1.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E/V
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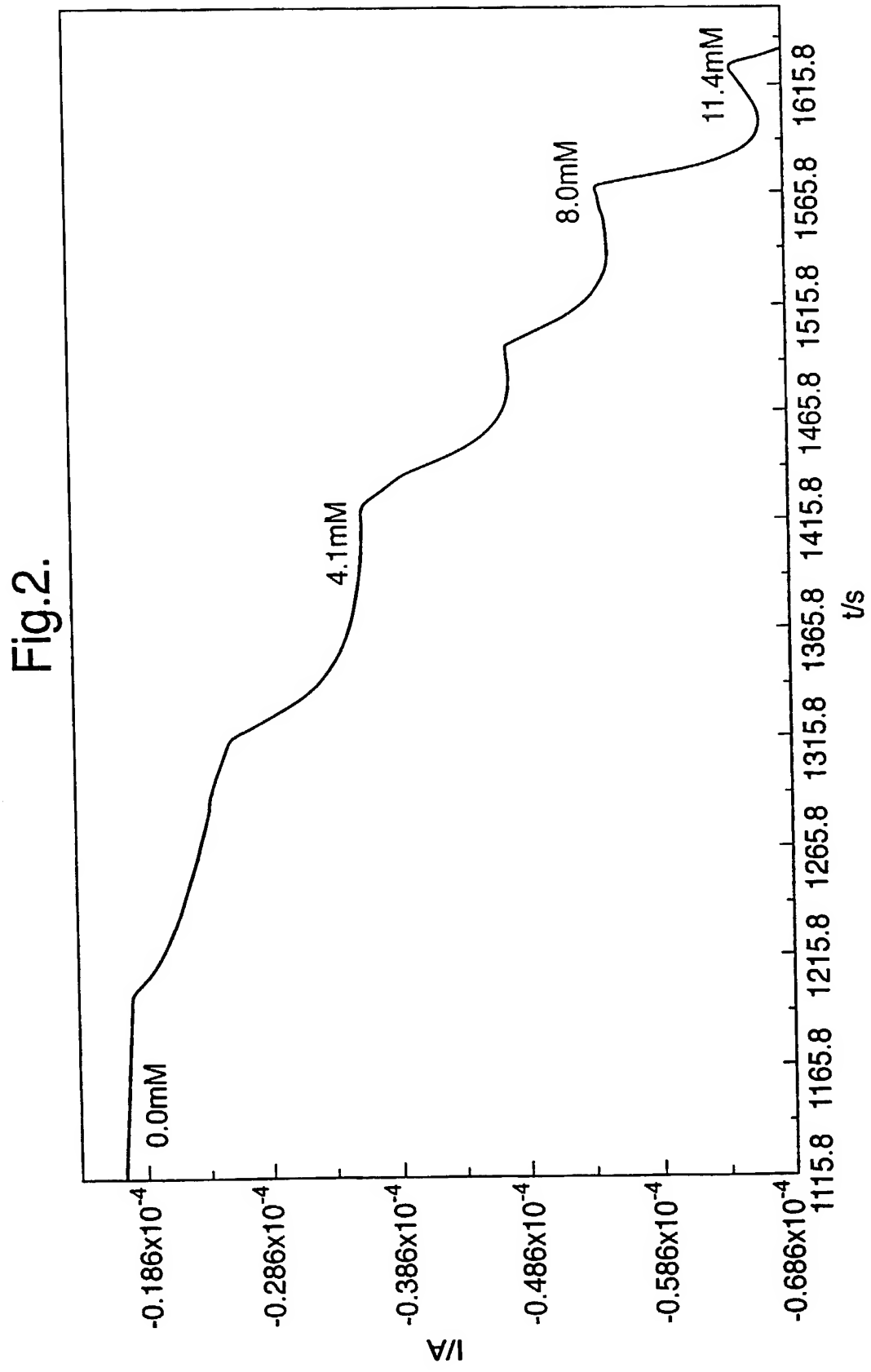
-1.250

Fig.2.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1165.8
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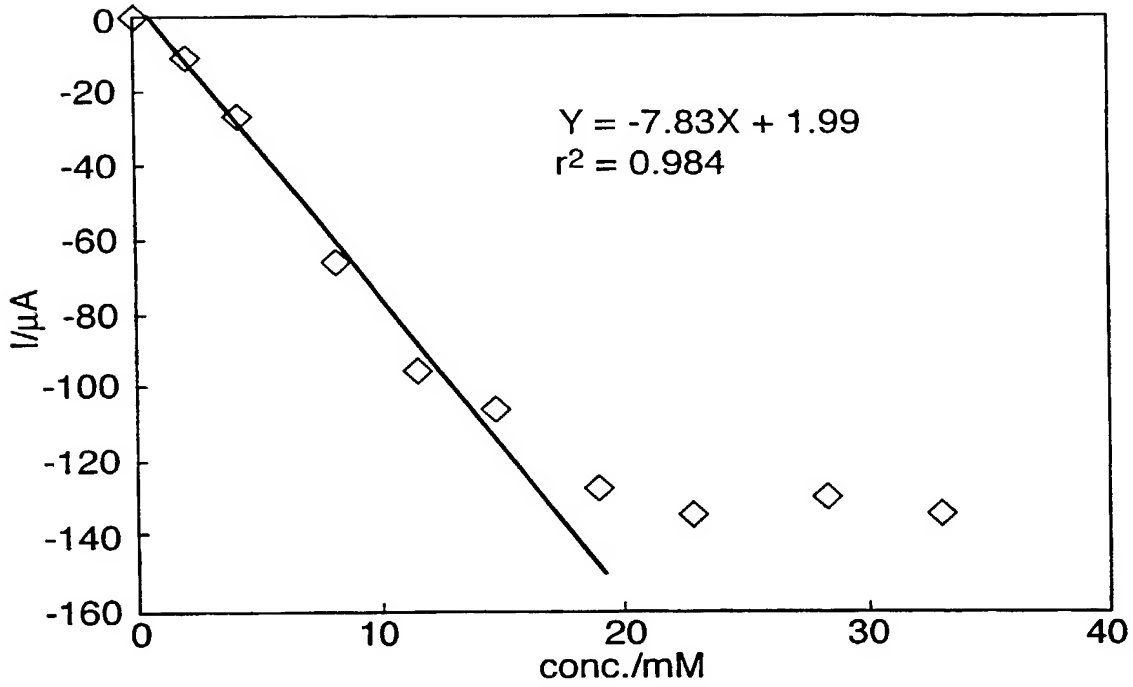
t/s

Fig.3.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conc./mM
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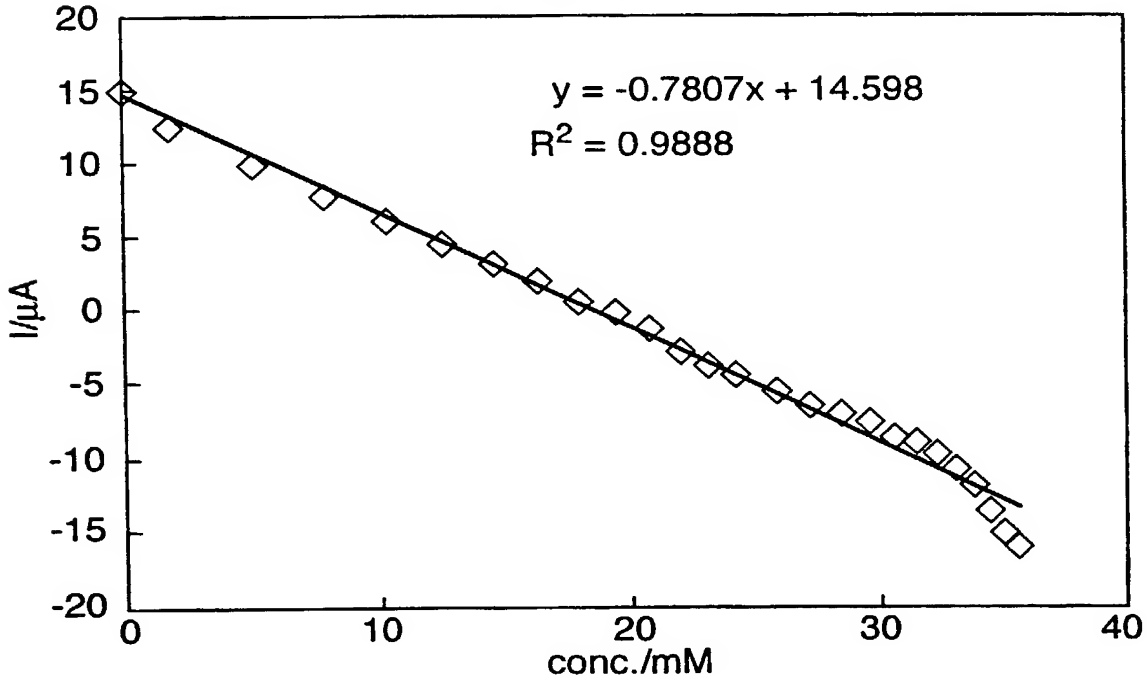
-140
-160
0
10
20
30
40

Fig.6.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R2 = 0.9888
I/µA
conc./mM
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15
10
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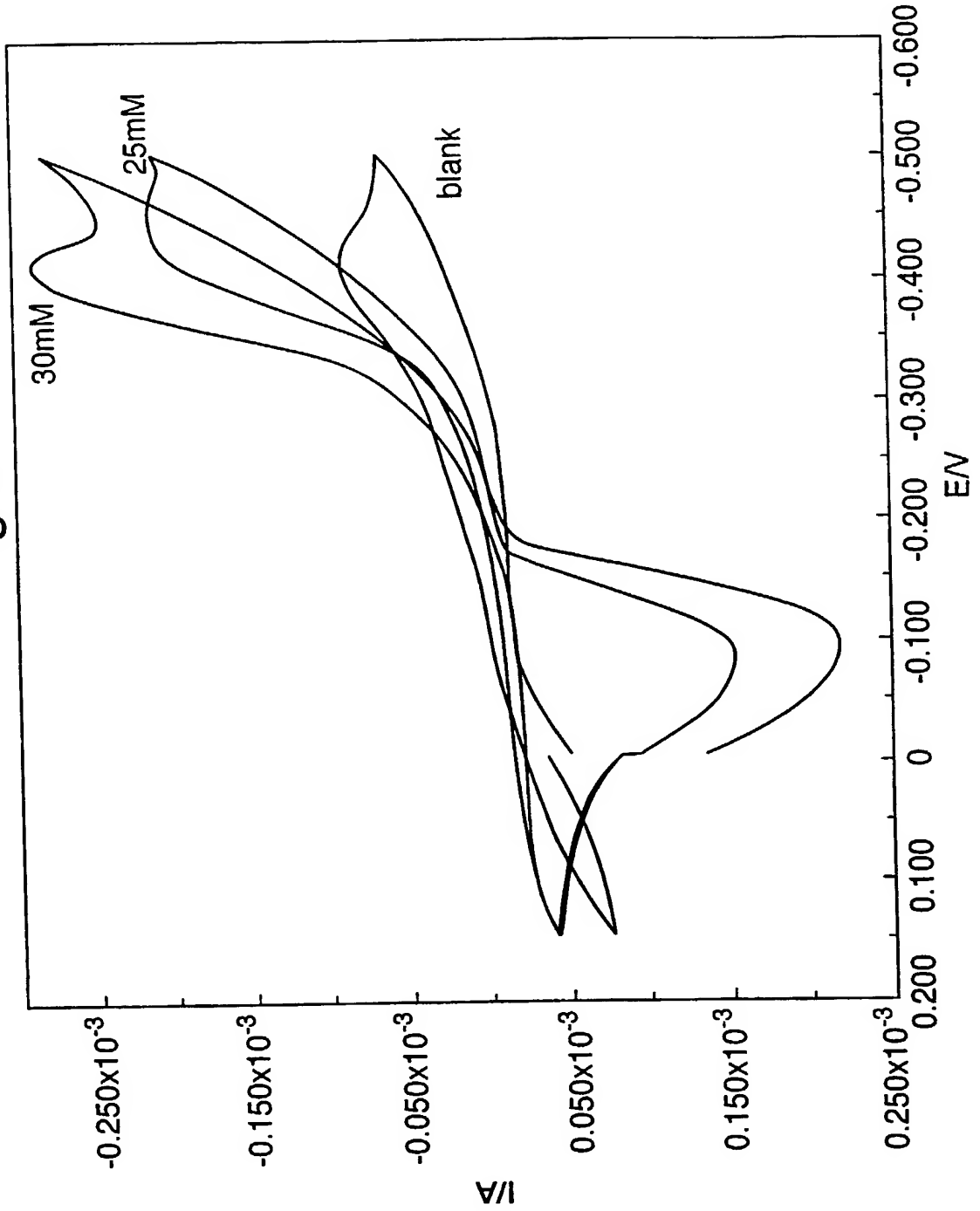
-15
-20
0
10
20
30
40

Fig.4.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-0.300
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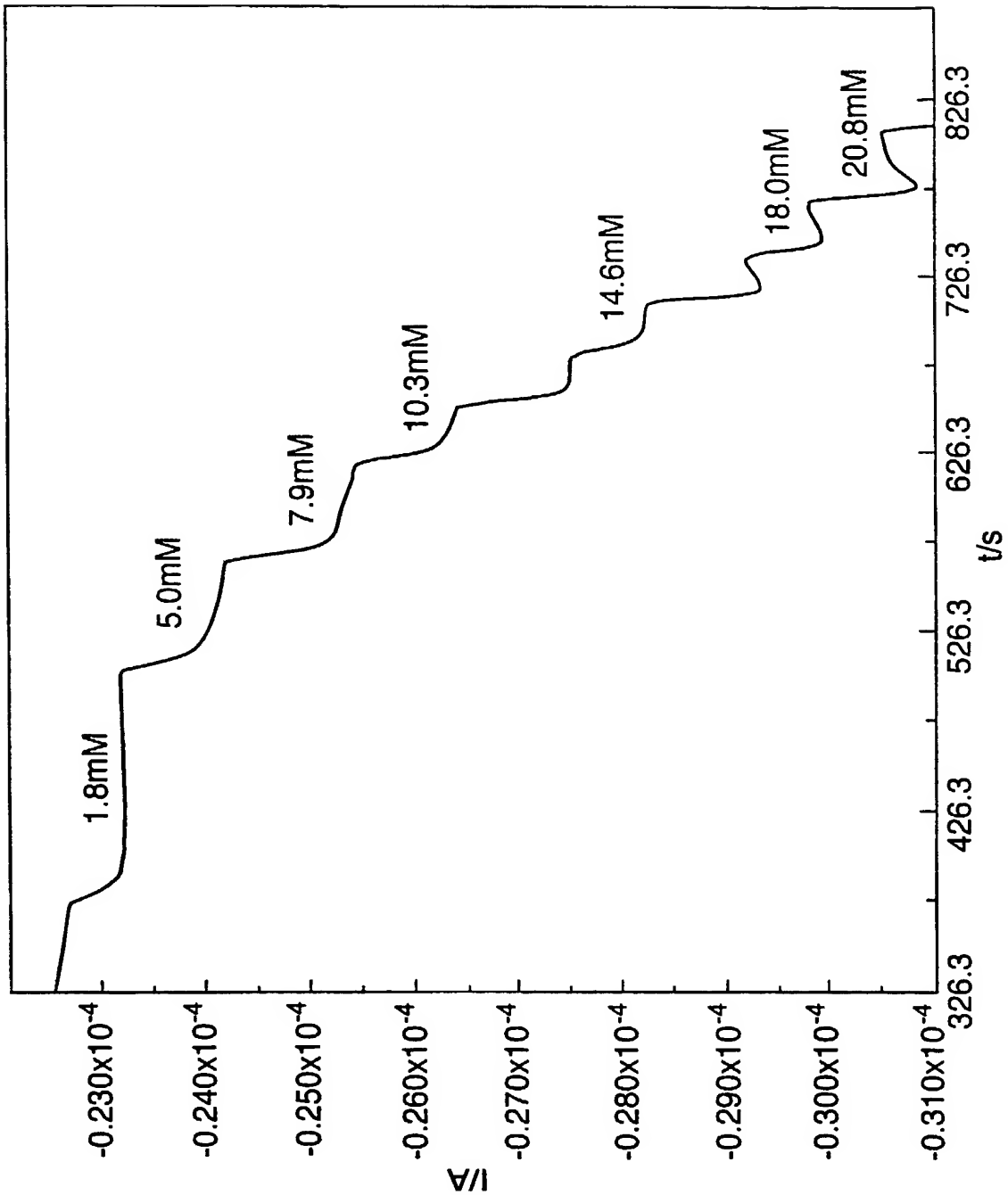
-0.600
E/V

Fig.5.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I/A
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526.3
626.3
726.3
826.3
t/s

N.77228B

Attorney's Docket No. 117-373

RULE 63 (37 C.F.R. § 1.63)
DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

As below named inventor(s), I/we hereby declare that

This declaration is of the following type:

☐ original	☐ design	☐ supplemental
☒ national stage of PCT		
☐ divisional	☐ continuation	☐ continuation-in-part

My/our residence, post office address and citizenship are as stated below next to my/our name.

I/we believe I/we am/are the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

AMPEROMETRIC SENSOR

the specification of which (check one)

☐ is attached hereto

☐ was filed on _____
in the United States Patent and Trademark Office as Application Serial No. _____
and was amended on _____ *(if applicable)*

☐ was described and claimed in PCT International Application No. **PCT/GB00/02504**
filed on **29 Jun 2000**
and as amended under PCT Article 19 on _____ *(if any)*

I/we hereby state that I/we have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I/we acknowledge the duty to disclose information which is material to patent ability as defined in 37 C.F.R. § 1.56.

I/we hereby claim foreign priority benefits under 35 U.S.C §119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate or under § 365(a) of any PCT International Application(s) which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate or PCT International Application having a filing date before that of the application on which priority is claimed:

COMBINED DECLARATION AND POWER OF ATTORNEY

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. §119

Application No.	Country	Filing Date	Priority Claimed	
			Yes	No
9915181.3	GB	29 Jun 1999	X	
PCT/GB00/02504		29 Jun 2000		

I/we hereby claim the benefit under 35 U.S.C. § 119(e) of any United States Provisional Application(s) listed below:

UNITED STATES PROVISIONAL APPLICATION(S)

Application No.	Filing Date

I/we hereby claim the benefit under 35 U.S.C. § 120 of any United States Application(s) or § 365(c) of any PCT International Application(s) designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International Application in the manner provided by the first paragraph of 35 U.S.C. § 112, I/we acknowledge the duty to disclose information which is material to patent ability as defined in 37 C.F.R. § 1.56 which became available between the filing date of the prior application and the national PCT international filing date of this application.

PRIOR UNITED STATES/PCT INTERNATIONAL APPLICATION(S)

Application No.	Filing Date	Status (patented, pending/abandoned)
PCT/GB00/02504	29 Jun 2000	

And I hereby appoint **Nixon & Vanderhye P.C., 1100 North Glebe Road, 8th Floor, Arlington, Virginia 22201-4714, telephone number (703) 816-400 (to whom all communications are to be directed)**, and the following attorneys thereof (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent: Arthur R. Crawford, 25327; Larry S. Nixon, 25640; Robert A. Vanderhye, 27076; James T. Hosmer, 30184; Robert W. Faris, 31352; Richard G. Besha, 22770; Mark E. Nusbaum, 32348; Michael J. Keenan, 32106; Bryan H. Davidson, 30251; Stanley C. Spooner, 27393; Leonard C. Mitchard, 29009; Duane M. Byers, 33363; Paul J. Henon, 33626; Jeffry H. Nelson, 30481; John R. Lastova, 33149; H. Warren Burnam, Jr., 29366; Thomas E. Byrne, 32205.

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I/we hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C § 1001 and that such willful false statements may jeopardise the validity of the application or any patent issued thereon.

COMBINED DECLARATION AND POWER OF ATTORNEY

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